# New Biocomposites for Innovative Construction Façades and Interior Partitions

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**Abstract**

*Osirys is a European Research Project where a holistic solution for façades and interior partitions ready to be applied in building retrofitting and new construction has been developed. The project uses biocomposites as the base material to define different products: a multilayer façade, a curtain wall, a window, and an interior partition. The biocomposites developed have different functionalities able to meet the strictest requisites of the European Building Codes in relation to fire and structural performance, improve indoor air quality through the elimination of VOCs (volatile organic compounds) and microorganisms, increase thermal insulation, and increase the durability of construction elements. The new systems are lighter than traditional ones, leading to reductions in overall weight, thereby reducing implementation costs during both manufacturing and assembly processes, thanks to an industrialised concept that utilises modular elements.*

*The project was developed with the collaboration of 18 European partners (5 research centres, 9 SMEs, 2 large industries, and 2 public bodies). The main activities were devoted to the establishment of requirements, the development of materials, the design of products, the integration of materials into products, the verification of properties by simulation and testing according to EU standards, the integration of products into real buildings, and economic and environmental assessment.*

*The scope of this paper is to provide a general overview of the entire project work and results to demonstrate the feasibility of using biocomposites in envelope solutions with the aim of solving some of the main problems that exist in façade traditional solutions. The project finishes with the implementation of the developments in real buildings as prototypes; further research is required before industrial scale manufacturing of the systems can be launched into the market.*

**Keywords**

*façades, curtain wall, biocomposite, multilayer façade, interior partition, windows.*

# 1 INTRODUCTION

Nowadays, several types of façade systems are used (traditional systems like brick façades, and steel and aluminium curtain walls). However, various problems are associated with these façades, as listed below:

- The use of steel and aluminium, materials with high thermal conductivity, demand the use of a different material to avoid thermal bridging. This requires the use of geometrically complex profiles and is therefore problematic for manufacture. New materials with better thermal attributes can improve this behaviour, with less complexity in geometry and manufacturability.
- The use of fossil resources and high energy consumption in the manufacturing process must be reduced. New materials from natural resources, such as bio-based materials, can accomplish a more sustainable production process and a better use of natural resources (eventually achieving a better result in relation to a circular economy in which all the materials and processes are connected during their entire life cycle).
- Many materials that are now on the market have problems in relation to the generation of contaminants (like VOCs, formaldehyde, fibres, and particulates). New materials that do not generate such contaminants are needed. Moreover, active materials that can eliminate this type of hazardous components and other elements, like microorganisms emitted by other sources, are required. This requirement is produced by an increased concern for indoor air quality in buildings, a requirement that will soon become more stringent due to new standards and regulations that are in the process of being approved in Europe.
- It is necessary to avoid the use of water on construction sites and to reduce the amount of sub-standard work normally involved in the construction of a building. It is essential to explore new solutions that have a high component of industrialisation and a modular approach, that avoid the use of water on-site and improve the quality of the final work by increasing work completed in the factory and reducing these works during the installation process. This also leads to higher skills amongst the workers that participate in the entire process.

Additionally, new possibilities related to design in the envelope should be explored. The use of new materials with different manufacturing processes can lead to new solutions that work better for building envelopes, avoiding the constrains of the current materials.

With the aim of solving the above-mentioned constraints, the Osirys project was developed. The aim of the project was to design a holistic biocomposite façade solution with better performance than traditional solutions. The selection of the biocomposite materials was done according to their performance with regard to thermal conductivity, design possibilities, absence of hazardous materials, industrialisation capacity, and reduction of use of fossil fuel resources, in comparison to metals, the current most widely used material. However, the use of a new material with different characteristics involves a complete redesign of the product geometries and construction process. Thus, the Osirys project starts with the development of different biocomposite materials, progressing through the design and manufacture of biocomposite products, and finishes with the testing and installation of these products in real conditions.

The project has been running for 4 years with the collaboration of 18 partners, of which there are 5 research centres, 9 SMEs, 2 industries, and 2 public bodies, from 11 EU countries. The consortium combines scientific and technological knowledge on materials and design to reach the goal of the Osirys project.

- The RTOs (Research and Technology organisations) focused on the development of materials, the improvement of their characteristics, environmental assessment, and validation of performance through standardised testing.
- The SMEs and industries up-scaled the laboratory-scale processes to semi-industrial processes to produce real-scale products, and developed the engineering and architecture to allow them to be installed in the demo buildings.
- The public bodies were in charge of the demo activities by using the products in real buildings. ] The methodology followed to obtain the final results during the execution of the project is explained below:

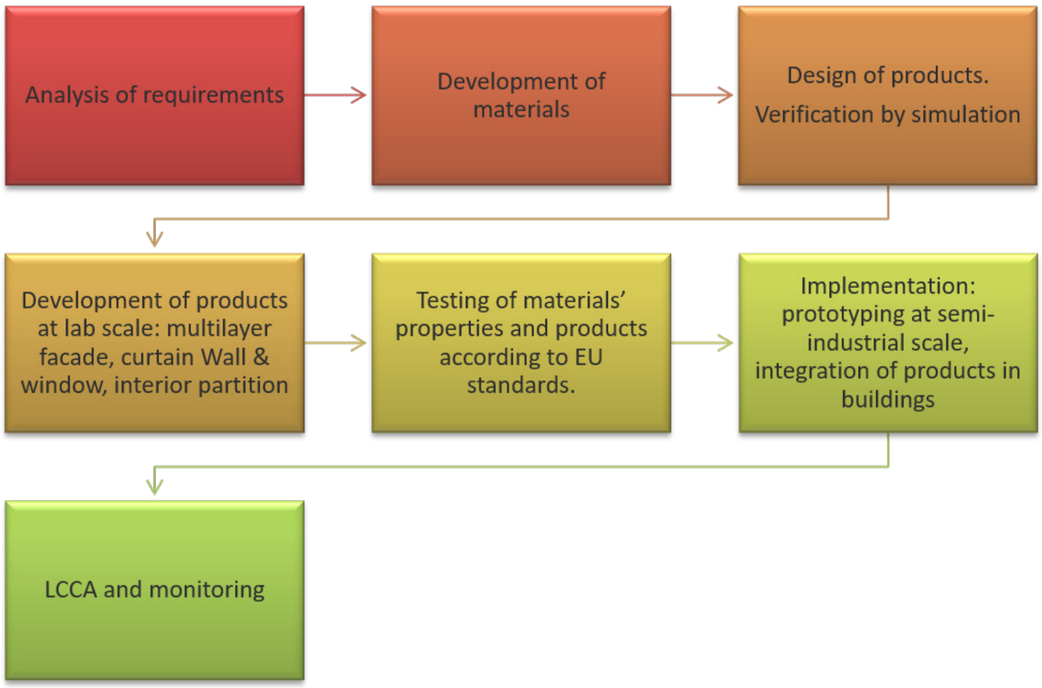


FIG. 1 Methodology to design and develop Osirys products

Taking into account these requirements, the following materials and products were developed in the project:

Materials developed for use as components of the final products:

- Light foam biocomposite: to be used as a base material for the internal layer of the different components developed. With improved thermal characteristics and less weight. Complying with building codes requirements.
- Natural insulator: to be used as an insulation component in the different systems. Improving fire behaviour without losing thermal characteristics.
- Biocomposites with improved mechanical and fire performance: one of the problems of the composites is their poor mechanical performance when compared to steel and aluminium solutions. New developments using different types of resins and fibres must be explored to avoid this problem. Moreover, the fire performance of these materials must be improved to reach the requirements of the European regulations.

- Biocomposites with good outdoor durability performance: to improve the outdoor performance of these materials to make them comparable with the existing systems on the market such as cladding elements for ventilated façades.
- Indoor multifunctional coating: to avoid the generation of contaminants and to improve active characteristics to eliminate the problematic components that are present indoors after construction.

Final components and systems, utilising characteristics of the new materials developed:

- Multilayer façade: an industrialised system with the aim of substituting traditional opaque façades (brick and concrete) for a lighter option, with better thermal, acoustic, and fire performance and with enough flexibility to be adapted to different building solutions. Mainly built in the factory, with a kit concept to avoid works on site.
- Curtain wall and window: a biocomposite curtain wall and window, with less complex profiles, better thermal performance, and high aesthetic flexibility. Moreover, this uses a modular and industrialised concept.
- Interior partition: a system to construct all the internal walls of a building with the new eco-materials, without losing the beneficial qualities of traditional systems.

With these new developments, the project offers a complete solution to be used in both envelopes and interior partitions, in many different types of buildings (mainly residential, as well as tertiary buildings such as commercial, administrative, and offices), overcoming the problems associated with current systems.

The aim of this paper is to provide a general overview of the Osirys project, to make readers aware of the innovations that can be achieved by using novel materials such as biocomposites for façades and interior partitions. So, the information provided in this article is not an exhaustive detail of each development and test, but intends to give general information and results about new possibilities when using materials other than steel and aluminium.

## 2 OBJECTIVES FOR THE DEVELOPMENT OF THE NEW MATERIALS AND SYSTEMS

The development of such novel systems requires the fulfilment of several objectives. The most relevant ones are detailed below:

- Development of a new photocatalytic coating to be active under indoor illumination, with protection against fire, and coloured. It was estimated that a VOC concentration reduction to <1mg/m3 and mould generation is can be reduced by a reduction factor of 5-6 logarithmic units in 12 hours.
- Development of a lighter system with weight savings of 70% compared to traditional brick and precast concrete walls.
- Development of an industrialised system to reduce implementation costs. Assembly works were expected to be reduced significantly.
- Fulfilment of the main requirements from the European Building Codes related to mechanical resistance, thermal behaviour, fire, and acoustic performance, etc. (see tables in the article)
- Biomass feedstock was above 60% in the multilayer façade and almost 70% without including fastening devices.

- Assumed price increase of the system over traditional products: comparable price for the curtain wall, 32% increase for the multilayer façade, and 15-20% increase for the interior partition.

# 3 WORK PERFORMED

In order to achieve these results, the Osirys project was divided into different research activities that are explained as follows:

## 3.1 ANALYSIS OF REQUIREMENTS

The main objective of this work is to establish and quantify the requirements to be met by the developed materials and products as a basis for further developments to be achieved in the following works. In this regard, the following requirements have been considered and analysed:

- Characteristics that the materials must fulfil
- Design requirements for products to facilitate construction
- Regulatory requirements affecting the materials and products
- Market requirements focused on market drive forces
- Definition of the most common types of buildings where the new developments can be implemented

Results from LCA studies most commonly show that raw material production has the greatest importance in the total environmental impact of a product. Thus, in order to keep the environmental impact of a product as low as possible, the impact from raw material production should be minimised. Materials based on biomass feedstock were considered for the replacement of existing petrochemical and other traditional materials. Natural fibres such as wood, cork, flax, and jute, and bio-based biopolymers were considered for the development of new materials and products.

A first set of guidelines to design the four products defined in the project (interior partition system, multi-layered wall system, window, and curtain wall) were established. This process considered both a prefabricated system combining all Osirys elements and a site assembled hybrid system where the elements can be combined with commercial systems. Each product is made by combining the different materials that were developed in the project according to their final function (i.e. the curtain wall comprises profiles, the interior partition includes profiles, insulation, and coating, etc.). Each element that comprised the four novel products was defined, along with its function. In addition, reuse and recycling concepts were also considered in the design process.

In accordance with Construction Product Regulation (EU) Nº 305/2011 (CPR), six Basic Requirements (BR) for construction works were checked to ensure that they are designed and executed so as not to endanger the safety of persons, domestic animals, or property, nor damage the environment. After analysing the requirements for the four products in various European countries, very demanding Osirys targets were set up. There is no specific regulation for indoor air quality, but various recommendations have been considered to minimise VOCs emissions and the growth of microorganisms.

Osirys products can be used in different types of buildings. Therefore, they were analysed for different building typologies (offices, residential, commercial, and culture/public), and were also related to building envelope types (multi-layered wall and curtain wall), while also considering the optimum U-value for each city/region of Europe.

## 3.2 DEVELOPMENT OF HIGHLY BIO-BASED MULTIFUNCTIONAL MATERIALS (TO BE USED AS THE BASIS FOR THE PRODUCTS DEVELOPMENT)

Within this work, several materials were developed, each one for a specific purpose.

Indoor multifunctional coating: The aim of this material was to decompose VOCs and introduce antimicrobial properties on indoor surfaces. First of all, a suitable method was developed, based on methylene blue to evaluate the photocatalytic activity of pigment powders and coatings under indoor lighting conditions. The developed coating showed good photocatalytic performance based on the methylene blue method; activity performance was higher than other commercial products. A testing setup to analyse antimicrobial properties was optimised. Results indicated that the new paints show very good antimicrobial activity against two selected microorganisms: Aspergillus niger (mould) and Sarcina lutea. To evaluate the fire performance of the coatings, cone calorimeter testing was carried out. The coatings did not ignite on aluminium substrates and did not contribute to the release of heat. When applied on organic substrates, the adhesion was good but it was necessary to add a fire retardant to the coating to reduce heat emission. Customers and architects are interested in having a coating with a range of colours, and so the coloration capacity of the coating was evaluated along with the stability of the colour after three months in both standard indoor conditions and extreme humidity conditions. Results showed that every colour is available in bright shades and remains stable over time.

Light foam biocomposite: The aim of this material was to develop a light foam biocomposite sandwich panel with good mechanical, thermal, and acoustic performance for use in interior walls. The surface panels that best promote mechanical and sound absorption properties were found to be porous wood fibre webs produced by a foam-laid forming technique. The core layer was formed by expanded biopolymer foam produced by extrusion to improve thermal and sound insulation properties. Initially, fibre material, additives, process parameters of foam forming, pressing and drying processes, and manufacturing procedures for fibre web production was tested and optimised. The formulations with the best performances were optimised and several tests were conducted and compared to traditional gypsum board. Lignin-based biopolymer foaming was possible at lab-scale, but up-scaling the process was unsuccessful. Therefore, PLA based biopolymer foam was optimised. PLA foam layers of 10-15mm thickness were obtained with a density of 60 kg/m3 and thermal conductivity in the range of polystyrene. Pilot scale layers were obtained. The thermal performance of PLA foam was better than commercial XPS.

| SAMPLE ID | THERMAL CONDUCTIVITY [W/MK] | THERMAL DIFFUSIVITY [$mm^2/s$] | SPECIFIC HEAT PER VOLUME [$MJ/M^3K$] |
|---|---|---|---|
| PLA FOAM 05/15 | 0.037 | 0.449 | 0.083 |
| XPS (Reference) | 0.033 | 0.573 | 0.057 |

TABLE 1 PLA foam thermal performance

Natural insulator: Cork materials were used as part of the sandwich panels to improve the thermal and acoustic performance of the final systems. Although cork is a natural material with fire resistance properties, agglomerated cork with different binders could affect the fire performance of the material. The main objective was to improve the fire performance of the cork materials. To do so, different fire retardants were included in the agglomerated materials. Samples were produced by block technology, cylinders, and double belt press. A small flame test was used as a screen process and the best formulations were tested in a cone-calorimeter to analyse the ignitability, the fire propagation, and smoke density. In general, the production line products showed worse fire reaction performance than laboratory ones. However, all the fire analysed retardants improved the fire-retardant properties of the samples.

Biocomposites with good outdoor durability performance: following research on different coatings, six commercial coatings have been selected (four colour coatings and two transparent coatings) for evaluation in terms of their suitability for improving the outdoor durability of the biocomposites in their use as ventilated façade cladding. Durability was assessed by testing the samples for 1000h in a QUV device. In addition, the mechanical performance of the coatings was also evaluated.

Biocomposites with improved mechanical performance: To increase the mechanical performance of the biocomposites to be used as profiles, graphene functionalisation was tested. A roll mill was selected as the optimum dispersion method of graphene in bioepoxy resin. It was possible to include a minimum percentage of nanofiller in the system without a substantial increase in viscosity. Afterwards, the pultrusion process at lab-scale was optimised as follows:

- Modifications to the pultrusion equipment to adapt to the curing cycle of the bioepoxy resin
- Processability evaluation of the bioepoxy resin with glass fibre and graphene
- Impregnation of the flax fibres by combining them with glass fibres, graphene, and a standard polyester resin
- Rebars with different formulations were obtained for mechanical testing
- Tensile tests of the biocomposites indicated that graphene does not improve mechanical performance of the materials and flax fibres did not reinforce as successfully as glass fibres. However, hybrid systems composed of flax fibres and glass fibres provided similar mechanical performance as glass fibres.

Biocomposites with good fire performance: Thermoset biocomposites were protected by three methods: coatings, the use of mats impregnated in a liquid flame retardant, the use of graphene. However, dispersion problems in infusion type bioepoxy hindered the use of graphene as a fire retardant. In pultrusion bioepoxy, the graphene contributed somewhat positively to the fire-retardant effect. In terms of protective coatings, all of the coatings tested for improved fire performance were tested by single flame test. The best candidates were tested in the cone-calorimeter. The intumescent coating showed the best results. In the case of thermoplastic biocomposites, different fire retardants and natural fibres were tested.

FIG. 2 Osirys products under testing (from top left, clockwise): fire resistance test for multilayer façade, acoustic test preparation, wind load test for the ventilated façade (external layer of the multilayer façade), Kubik testing for thermal properties,)

## 3.3 INTEGRATION OF MATERIALS INTO COMPONENTS

The overall objective of this part of the work is to combine the different materials developed previously into the final components.

<u>Manufacture of sandwich structures</u>: The different materials developed by Osirys partners were characterised with respect to their thermal, mechanical, and viscoelastic properties, and combined to produce multilayer sandwich panels. Overall, these multilayer sandwich panels performed well,

indicating their potential for use as partition walls, interior separation panels, and cladding panels in buildings. Their low density and the known properties of thermal insulation, acoustic insulation, and low hygroscopicity given by the configurations tested contribute to the value of these sandwich panels for the planned project demo cases in construction.

Evaluation of assembly properties: The aim was to develop an adhesive that can improve indoor air quality by achieving low VOC emissions while offering a good bonding solution for the sandwich structure. Adhesives provide some benefits over mechanical fasteners, like lower structural weight, lower fabrication cost, and improved damage tolerance.

Manufacturing and testing of lab-scale prototypes: Different configurations were produced with a variety of previously developed sheets, core materials, profiles, coatings, and adhesives, and were assembled to provide a wide range of solutions for the case studies proposed: internal partition and multilayer façade. The multilayer façade was divided in 3 sections: interior finish, multi-layered core module, and exterior finish panel. In order to choose the most suitable configurations, the thermal conductivity of the internal partition and interior finish was tested. Results indicated that the range of thermal insulation of the interior partition was similar to mineral wool and EPS, and that of the interior partition was similar to the use of natural fibres. With these results and the design results, the final configurations for lab-scale prototypes were set up.

| PERFORMANCE | TEST | STANDARD | RESULT | COMMENT |
|---|---|---|---|---|
| Structural safety | Impact resistance to soft body | EOTA Technical report TR001, section 2 | E= 500J, 1200J<br>Permanent denting of the outer layer. No breakage or release of elements | OK<br>No breakage |
| Impact resistance to hard body | | EOTA Technical report TR001, section 3 | E= 5J, 10J<br>No damage | |
| Protection against noise | Acoustic insulation | EN ISO 10140-2 | $R_w$= 54 dB | OK<br>Average with commercial products |
| Thermal insulation | Thermal Transmittance | Theoretical calculus | U=0.127 W/m$^2$K for the complete system<br>U=0.193 W/m$^2$K without XPS | OK to targets defined by demo owners<br>$U_{tartu}$=0.14<br>$U_{spain}$=0.25 |
| Air permeability | Air permeability | EN 12114 | Class 3<br>0.034 m$^3$/hm$^2$ at (+/-) 55 Pa | OK<br>Values according to low energetic consumption buildings |
| Water tightness | Water vapour transmission | EN ISO 12572 and theoretical calculus | $\mu_{cork}$= 40<br>$\mu_{WPC}$=1,700<br>$S_{d,total}$= 40m (3) | OK<br>Breathable and non-breathable layers |
| Fire safety | Fire resistance | EN 1363 | EI90 | OK to target EI60 defined in the project |
| | Reaction to fire | EN ISO 11925-2 | Bs2d0 | OK to the target defined |

TABLE 2 Resume of the obtained test results on lab-scale sandwich systems

## 3.4 DESIGN OF CONSTRUCTION SYSTEMS FOR FAÇADES AND INTERIOR PARTITIONS

Building typologies scenarios: Several façade typologies of buildings in Europe were studied and classified to set up a guideline to assist in the design of the new products. Two façade groups were defined according to the main uses of buildings (residential or office buildings), and within each group several typologies were defined according to the construction method. Thus, the main features and characteristics of each constructional solution have been studied, taking into account the climatic zone, the year of construction, and other parameters. Conclusions drawn from the study are summarised below:

- Residential building conclusions:
  - The 67% of the European residential building stock that was built before 2005 comprises a heavy resistant wall (such as concrete or cored brick), often covered with an exterior overlay and an interior plaster, but with no air chamber and with no insulation.
  - Almost 50% were constructed between 1946 and 1990 (post-war buildings) in Southern Europe (31.7 %) and in Central Europe (15%) and 15% are classified as old buildings
  - 28% of the residential buildings are composed of a heavy resistant wall with an unventilated air chamber filled with insulation.
  - Most of these were constructed between 1946 and 1990, mainly in Central Europe
  - Among the current building construction trends in South Europe, 50% of the façade typologies are ventilated façades, which comprise a resistant wall, a discontinuous overlay, a ventilated air chamber, and insulation to the outside.
  - Almost 40% of current residential buildings are composed of a heavy resistant wall with an unventilated air chamber that is filled with insulation.
- Office buildings conclusions:
  - Among the current office building construction trends, 35% of the typologies constructed are stick-system curtain wall façades, which are the most commonly used construction solution in South Europe and Central Europe.
  - This prevalence of this system is followed closely by the unitised curtain wall system.
  - Double skin systems are becoming more common on the market due to the higher importance of energy efficiency and reduction in energy consumption (zero-energy buildings).
- Conclusions drawn from the study of the residential buildings have been taken into account in the design of the multi-layered façade solution and the biocomposites window design, while the conclusions obtained from the analysis of office buildings have been used for the design of the curtain wall product.

| CONCLUSIONS FOR THE OSIRYS MULTI-LAYERED FAÇADE | | |
|---|---|---|
| GEOMETRIC FEATURES | Floor to floor height (m) | 3.0 |
| | Free floor height (m) | 2.5 – 2.6 |
| | % Window / Façade Ratio | 30% |
| FAÇADE DESCRIPTION | Thickness (cm) | 35 - 40 cm (up to 2005)<br>23 - 29 cm (new trend) |
| **CONCLUSIONS FOR THE OSIRYS CURTAIN WALL** | | |
| GEOMETRIC FEATURES | Floor to floor height (m) | 3.8 – 3.9 |
| | Free floor height (m) | 3.0 |
| | Façade modulation (m) | 1.8 |
| FAÇADE DESCRIPTION | Thickness (cm) | 20 |
| | % With solar protection | 20 % |

TABLE 3 Conclusions to be used in the design of Osirys products

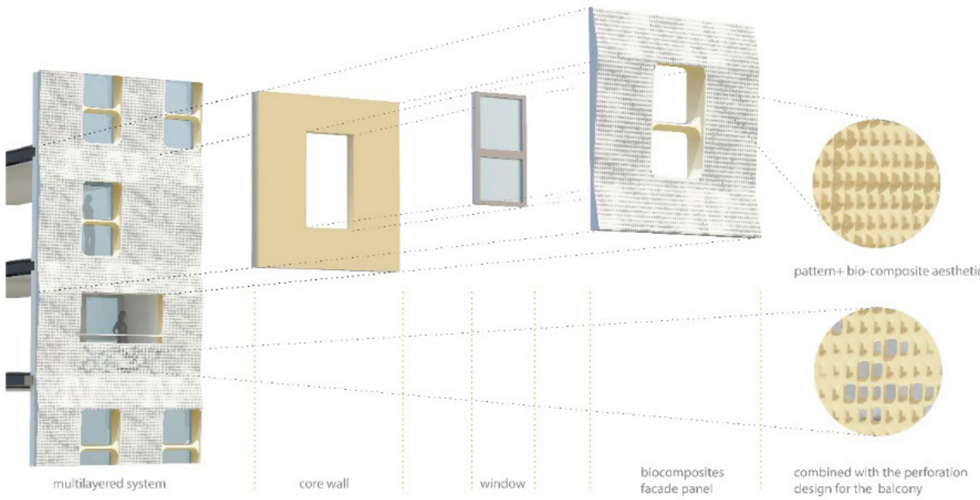


FIG. 3 Multilayer façade system components

Multilayer façade design: The developed multilayer façade system combines three main sections: internal finishing, core of the wall (multi-layered module), and external cladding. Each section consists of several elements developed within Osirys and combined together to create a fully functional building envelope.

- The assessment process used to verify the different products of the Osirys project comprises the following steps:
  - Initial design of the system
  - Structural and thermal simulations
  - Laboratory prototype construction and testing
  - Breathability, moisture, and presence of fungus and micro-organism simulations
  - Final design of the product
- Computer simulations provided important information showing that the design of the multilayer façade system comprising novel elements developed within the Osirys project fulfils necessary and crucial requirements like structural stability and proper thermal performance. Hygrothermal performance analysis of the multilayer façade panel under northern climate conditions was also assessed and results indicated that a vapour resistant membrane (moisture barrier) in cold (northern climate) was necessary to avoid moisture accumulation in the structure.
- With these results, the final design for the multilayer façade was provided element by element and also per system. The final designs also included the design of the connections between the Osirys elements, and between Osirys elements and non-Osirys elements, to integrate the new products in the demo buildings.

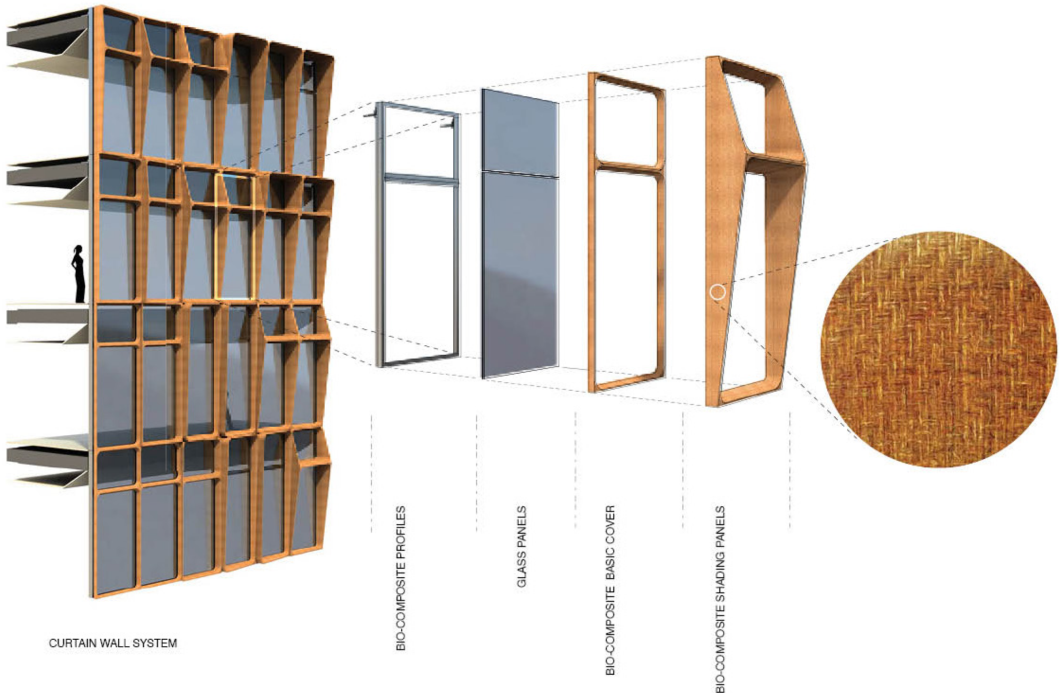


FIG. 4 Curtain wall façade system components

Curtain wall and window design: Different possibilities have been evaluated to find the best solution. The dimensions for prototyping are 3.8m high x 1.2m wide. The preliminary system design included the configuration and schematic definition of components, the study of the interactions of system components, and building systems and modularity. Like the multilayer façade design, structural and thermal simulations were performed to validate the final design according to the defined requirements. For the final design the following aspects were considered:

- The complexity of the profiles was reduced to avoid problems in manufacturing. A total of 3 profiles were designed for the curtain wall.
- For the window frame, a pultrusion profile with an operable part was designed.
- The final glass types were selected for the curtain wall and the window, and outdoor features for the Tartu Demo were decided.

Partition system design: After analysing the types of partition walls, it was decided to focus on a stud wall hybrid system, which is a fusion of a system assembled on-site and a prefabricated sandwich partition panel, which provides particular construction advantages. The partition wall is divided into two main components: structural profile and sandwich wall board.

- Structural biocomposite profiles are designed based on a standard, C-profile: aluminium structure with a width of 50mm, height of 60mm, and wall thickness of 5mm.
- The second component of the partition wall is the sandwich wall board. Different partition layers are combined together into one prefabricated panel mounted directly on to pultruded studs. The panel will ensure that all necessary properties that are to be fulfilled by partition walls are met. It will comprise bio-based acoustic and thermal insulation as well as a wall board that works as a wall lining. The width and cut edges of the panel are adjusted to the correct shape, and the distance between pultruded profiles is 400mm.

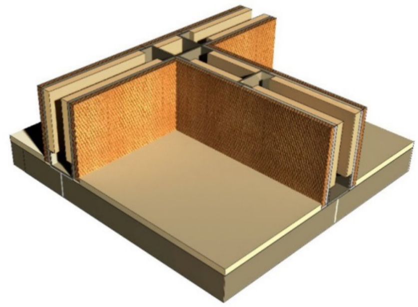

FIG. 5 Detail of the interior partition system

Laboratory prototype construction and testing: Full size prototypes were manufactured and validated under European Standards to verify that the Osirys products can be used in the demo buildings without legal problems regarding their final behaviour onsite.

A resume of the final results for the fourth systems can be found in the following tables.

| ESSENTIAL CHARACTER-ISTIC | STANDARD | EUROPEAN STANDARDS MINIMUM REQUIREMENT | OSIRYS FINAL RESULT |
|---|---|---|---|
| Reaction to fire | EN 13501-1 and Test under EN 13823 | B-s2-d2 | B-s2-d0 |
| Fire resistance | 1364-3 and EN 1364-4. Classification by EN 13501 | EI60 | EI90 |
| Watertightness | EN 12865 | 150A | 300A |
| Wind load resistance (services loads) | ETAG 034 | Depending of the building (façade classified) | 1800Pa (P) 1400 (S) |
| Mechanical resistance | ETAG 034 | Category IV | Category I |
| Horizontal point loads | ETAG 034 | | |
| Impact resistance | ETAG 034 | | |
| Airborne sound insulation | EN ISO 140-3 | Depending of the building and the situation (33 dB in some cases) | 53 dB |
| Thermal resistance | EN ISO 10077-2 | 0,25-0,35 $W/m^2K$ | 0,139 $W/m^2K$ |

TABLE 4 Multilayer façade results

| ESSENTIAL CHARACTER-ISTIC | STANDARD | EUROPEAN STANDARDS MINIMUM REQUIREMENT | OSIRYS FINAL RESULT |
|---|---|---|---|
| Water permeability | EN 12155 | R4 | R7 |
| Wind resistance (Service loads) | EN 12179 | Depending of the building (façade classified) | 1200 Pa (P) 1200 Pa (S) |
| Self-Weight | | L/500 or 3mm | L/500 or 3mm |
| Airborne sound insulation | EN ISO 140-3 | Depending of the building and the situation (33 dB in some cases) (*) | 40 dBA |
| Thermal transmittance | EN 13947 | Depending of the building and the situation (2 $W/m^2K$ in some cases) (*) | 1,04 $W/m^2K$ |
| Air permeability | EN 12153 | A1 | A2 |

TABLE 5 Curtain wall results

| ESSENTIAL CHARACTERISTIC | STANDARD | EUROPEAN STANDARDS MINIMUM REQUIREMENT | OSIRYS FINAL RESULT |
|---|---|---|---|
| Water permeability | EN 1027 | 1A | 3A |
| Wind resistance | EN 12211 | 600 (Pa) | 3000 (Pa) |
| Self-Weight | | L/500 or 3mm | L/500 or 3mm |
| Airborne sound insulation | EN ISO 140-3 | Depending of the building and the situation (33 dB in some cases) (*) | 40 dBA |
| Thermal transmittance | EN ISO 10077-2 | Depending of the building and the situation (1,2 to 2 $W/m^2K$ in some cases) (*) | 1,15 $W/m^2K$ |
| Air permeability | EN 1026 | Class 1 | Class 3 |

TABLE 6 Window results

| ESSENTIAL CHARACTERISTIC | STANDARD | EUROPEAN STANDARDS MINIMUM REQUIREMENT | OSIRYS FINAL RESULT |
|---|---|---|---|
| Reaction to fire | EN 13501-1 and Test under EN 13823 | C-s2-d0 | B-s2-d0 |
| Fire resistance | 1364-3 and EN 1364-4. Classification by EN 13501 | EI60 | EI90 |
| Resistance to dynamic loads | ETAG 003 | Category 2A (Residential) Category 2B (Offices) | Category 2A (Residential) Category 2B (Offices) |
| Resistance to eccentric vertical loads | ETAG 003 | | |
| Resistance to point loads | ETAG 003 | | |
| Airborne sound insulation | EN ISO 140-3 | Depending of the building and the situation (33 dB in some cases) | 47 dB |

TABLE 7 Interior partition results

## 3.5 DEMONSTRATION ACTIVITIES

Different activities were performed during the project to verify the final behaviour, in real conditions, of the developed products. These activities were divided into three main demos:

Demonstrator in KUBIK test building: The KUBIK facility (from Tecnalia) is a three-storey high building with a basement floor in which HVAC systems are located. An enclosed east-facing room on the ground floor is dedicated to the Osirys project. A prototype of the Osirys multi-layer façade was successfully prefabricated (wall core) and erected on site (wall core, external cladding, and internal part of wall), validating the construction process of the wall. Together with the on-site assembly process, a number of sensors were installed, allowing an experimental campaign for the measurement of the thermal performance of the multi-layered wall.

FIG. 6 Multilayer façade installed in Kubik test cell

<u>Demonstrator in a real building: Case study 1: Public building in Northern Europe:</u> The Tartu demo building is a 250m$^2$ stadium building located at Mart Reinik High School in the central area of Tartu (Estonia). The demo building consists of 4 dressing rooms, 2 shower rooms, 2 saunas, office space for teachers or referees, and a dressing room for the referees. The building will serve around 1200 students from 3 nearby schools. It will also be used by around 300 recreational users every week throughout the year.

— Firstly, the architectural design on Tartu demo building was carried out. The technical design of the Tartu demo building was finished after all details and joints between Osirys products and the other building materials were agreed. The HVAC design was also accomplished.

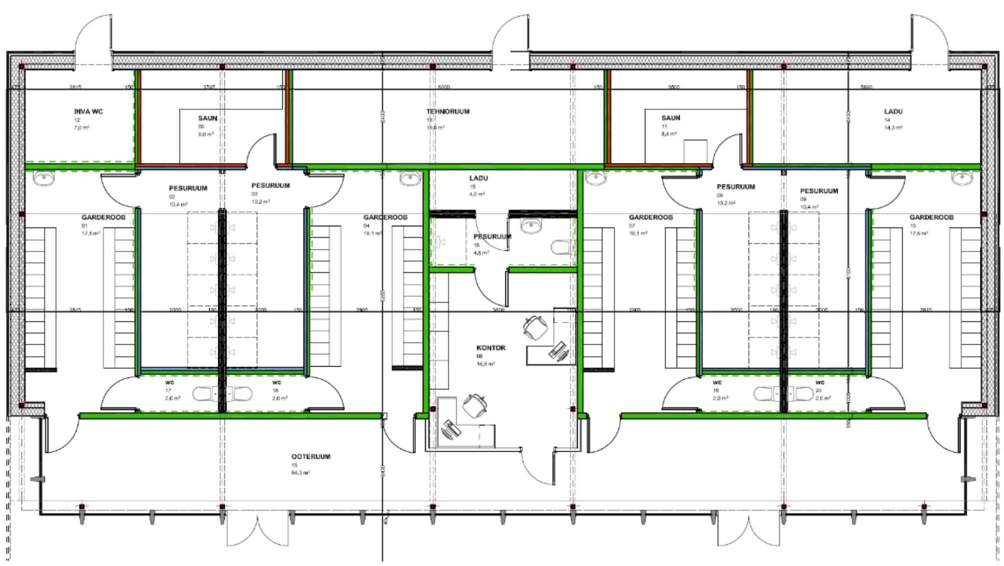


FIG. 7 Floor plan of the Tartu building

- Osirys systems (multilayer panel, interior panels, and curtain wall) were successfully installed quickly and simply, despite some on-site works being required due to the handcrafted nature of the products. Thus, the feasibility of using Osirys products in buildings was demonstrated, although optimisation of the industrialisation process and aesthetics is required for further commercialisation.

FIG. 8 External view of the Tartu demo building. The front curtain wall was developed through the Osirys project like the rest of the façades (which use the multilayer façade solution). The partitions inside the building also use the Osirys developments.

- Demonstrator in a real building: Case study 2: Residential building in Southern Europe, promoted by the partner VISESA (Basque Government): The demo building is located in a social housing block in San Sebastian (north of Spain). The construction plot is rectangular in shape (69 x 12m), with a slope of 4%, it consists of 2 underground floors + ground floor + 7 floors + attic and has 10 apartments per floor (total of 70 apartments). The apartment in which the Osirys products would be installed was selected on the south-east corner, at second floor level. It comprises two bedrooms, bathroom, kitchen and living room.

FIG. 9 Second floor of the San Sebastian demo building with the Osirys apartment highlighted

- The installation of Osirys products had to overcome barriers related to the inexperience of the construction team handling and working with this type of materials. So, to help the working teams with the installation of the systems, a guide for design and maintenance was prepared.

FIG. 10 Render of the final solution for the San Sebastian demo

## 3.6 MONITORING RESULTS FOR ALL DEMO BUILDINGS

Indoor air quality: Concentration of nitrogen dioxide and ozone were below the recommended guideline values for indoor air in the 3 demo sites and the indoor-to-outdoor ratios were < 1, indicating efficient removal of these compounds from outdoor to indoor air. TVOC measurements indicated that without ventilation it takes 7 weeks to reach a safe concentration of 300 µg/m3 as recommended in the guidelines. However, when slight ventilation of 23 $m^3$/h (corresponding to approx. 0.77 air exchanges per hour) is applied, even the initial TVOC concentration decreases to 500 µg/m3 and the time required to reach the safe level is reduced to 5 weeks, approximately half of the time required by a commercial coating to reach the same safe level. According to the TVOC guidelines issued by the German Federal Environmental Agency, painters will be exposed to indoor air of moderate quality. Thus, ventilation is adequate to provide a safe workplace. On the other hand, it was also observed that without lighting TVOC concentration increased, showing the photocatalytic effect of the coating upon indoor lighting.

Thermal performance: A thermal transmittance U-value of 0.160 $W/m^2K$ was estimated for the plane areas of the multi-layer wall. The measured U-value keeps within the same range as expectations from numerical calculations, with a slight increase of 0.021 $W/m^2K$, which is commonly found in physical measurements and can be attributed to workmanship issues or measurement errors, among others. The measured thermal performance confirms that the Osirys multi-layer wall is a well-insulated assembly that can work in any European climate and complies with requirements of all national regulations. Infrared images, together with the constant temperatures measured, showed that the multi-layer wall keeps a uniform temperature across its area, and the thermal bridging effect of the biocomposite profiles is very low. Relative humidity measurements indicate no moisture accumulation. Localised moisture spots dried out during this period, which is an indication of good drying capacity.

Life cycle assessment: The environmental performance of the multilayer façade, curtain wall, and interior partition was assessed. Each product was defined according to its elements and materials, and the weight per $m^2$ of wall and bio-content were quantified. Despite there being no similar products to

Osirys on the market, the following benchmark products were used for comparison because of their extended use or similarity to Osirys developments:

- Multilayer façade: brick wall façade. Traditional façade system used throughout Europe.
- Curtain wall: Glass façades of Fiberline composites. A product that could be comparable to Osirys products due to the use of composite materials.
- Interior partition: Knauf Aquapanel indoor panels. Gypsum panels with metal profiling.

The environmental assessment included the analysis of these parameters:

- Biomass feedstock: The bio-content of the products increased from around 1% of benchmark products to above 30% and 40% in the curtain wall and interior partition, respectively, and to almost 70% in the multilayer façade with 0.14 W/m2K, corresponding to the materials developed in Osirys (without glass or fastening devices). These results indicate the high value of the Osirys products in relation to their use of natural materials.
- Embodied energy: Because no multilayer façade comprising similar materials exists on the market, the wood-plastic fire-retardant panel included in the multilayer façade (that can be also found as fossil-based/traditional materials in the market) was chosen for comparison. Results indicated that the embodied energy in the fire-retardant wood plastic composite (WPC) panel was 161 MJ/m2, while in the conventional WPC it was 232 MJ/m2. The Osirys product was thus 31% lower in the content of embodied energy than the WPC.
- The weight of the new systems has been significantly reduced in comparison to commercial benchmark products: 78% for the multilayer façade, 50% for the interior partition, and 10% for the curtain wall.

## 4 FINAL CONCLUSIONS

The project is a first step to introduce new materials in the envelope sector, trying to solve some of the problems found in the traditional solutions or that are solved with more complex systems. The technical viability of using biocomposite materials on constructional elements to be applied in different European climates, assuring more comfortable buildings regarding energy efficiency and indoor environmental performance, has been assessed. The main result shows that new materials can be used in façades without major problems and that they can provide new characteristics and possibilities to the envelopes sector. Three real examples of their good behaviour can be shown in the demos of the project. Therefore, the demo buildings are a showcase for the developed novel products.

The best results are obtained in terms of the thermal characteristics of the systems. The solutions developed are simpler than the traditional ones (easier for manufacture), with better thermal behaviour, with more flexibility to be adapted to different climate conditions without major changes, and with fewer problems related to condensation and corrosion. Fire performance results are also in line with European requirements. Moreover, the creation of a façade identity by using biocomposite materials allow differentiation of the building works.

The environmental results are very promising as defined in the monitoring results.

The project is now finished. Some additional research is needed to improve both the mechanical characteristics of the materials and design to increase performance such as acoustic, air permeability, watertightness, and wind resistance. However, these problems can be easily overcome due to the good behaviour of the materials. The consortium is willing to continue working on improving the performance of the products in a further research project.

As soon as industrialisation of manufacturing processes is completed, these novel products can be launched into the market. Furthermore, the design process has considered the possibility of combining the different new elements with traditional systems to facilitate market penetration.

Likewise, some materials like the photocatalytic coating, the low-VOC adhesive, and the insulation cork have already been commercialised. Other products are under a patent process to be marketed.

Future publication will include a detailed explanation of the different activities developed in the project.

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